Challenges and Opportunities of Brain-Machine-Interfacing… An Industry Perspective

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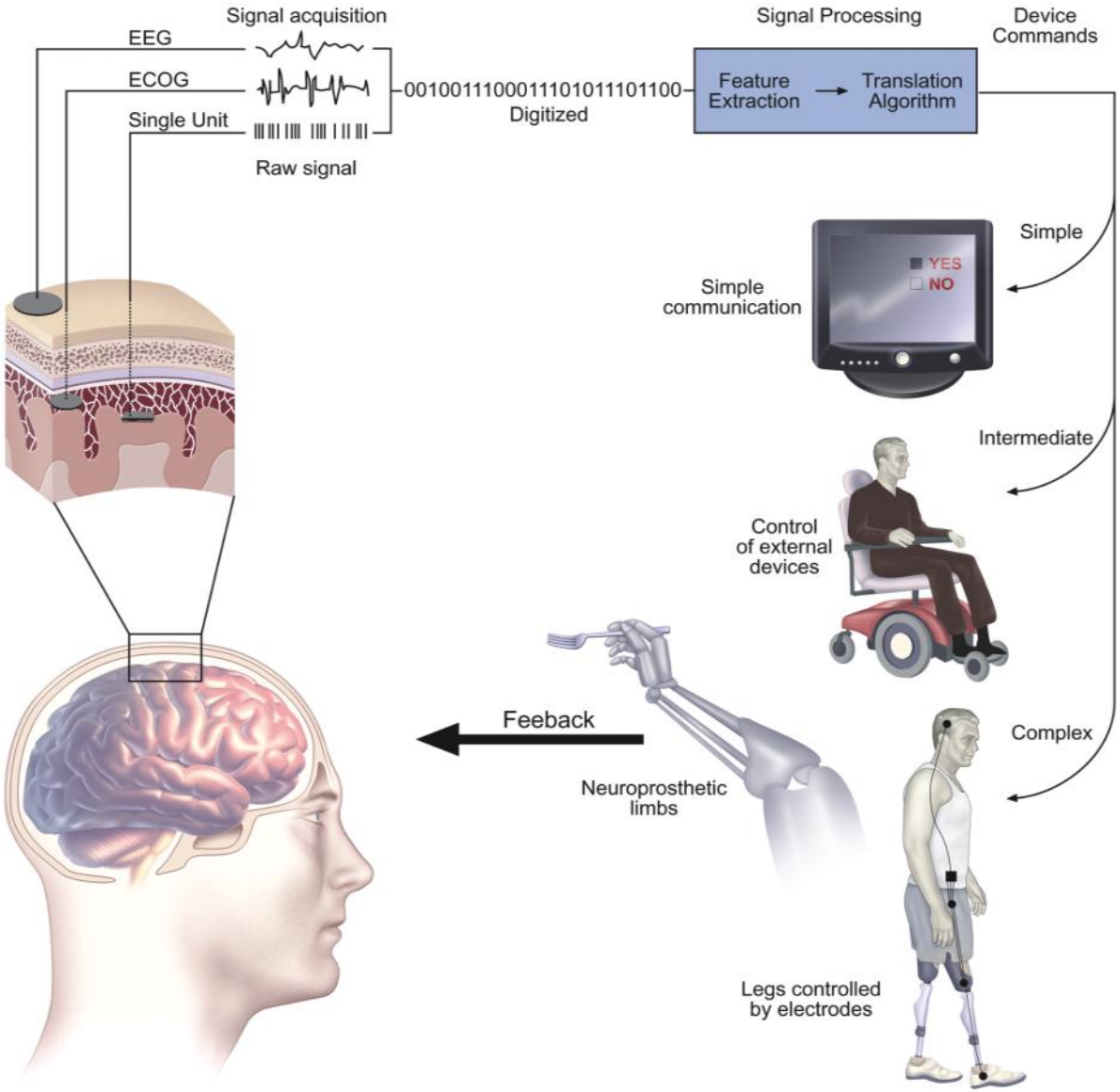
Medtronic Neuromodulation

Disclosures/Conflicts

- This is an invited “roadmap” technology talk, which by definition is forward-looking. Many technologies and concepts are therefore investigational, and are not approved for commercial sale in the US. *Assume all systems described are restricted to investigational use!*
- Thanks to Investigator-Sponsors: Drs. Phil Starr and Nicki Swann, from UCSF for kindly allowing us to share data from their investigator-initiated trial; Professor Howard Chizeck, Drs. Ojemann and Ko, and Jeffrey Herron, U-Washington, for sharing their algorithmic concepts; Professor Gregoire Courtine and the NeuWalk project for sharing pilot design concepts and experimental data.
- Tim and Scott are employees and shareholders of Medtronic, Inc. but are trying to stay agnostic to and speak for general industry trends and opportunities.
- Tim and Scott have IP in the area of neurotechnology, some captured in this presentation, particularly for sensing and algorithms for closed-loop neural systems.

Concepts for Brain-Machine-Interfacing
This Talk: Thoughts on *Translational Roadmaps*



Leuthardt et al, Neurosurgery, 2006

Framing 1: Needs and Constraints in Medical Technology

- Proof of clinical value
- Broad coverage

Healthcare Economics

- Severe disease with high QoL impact
- Few alternatives

Unmet needs

Evidence/ Science

- Good evidence from clinical studies
- Able to articulate/ educate on MOA

Ease of use

- Minimally invasive procedure
- Good patient usability
- Clinical support

Robust Technology

- Ready for “prime time”
- Has synergy with existing product portfolio and clinical experience

Framing 2: *Consideration of Delivering **Value***

Results + Process Quality

Customer Access Costs + *Price*

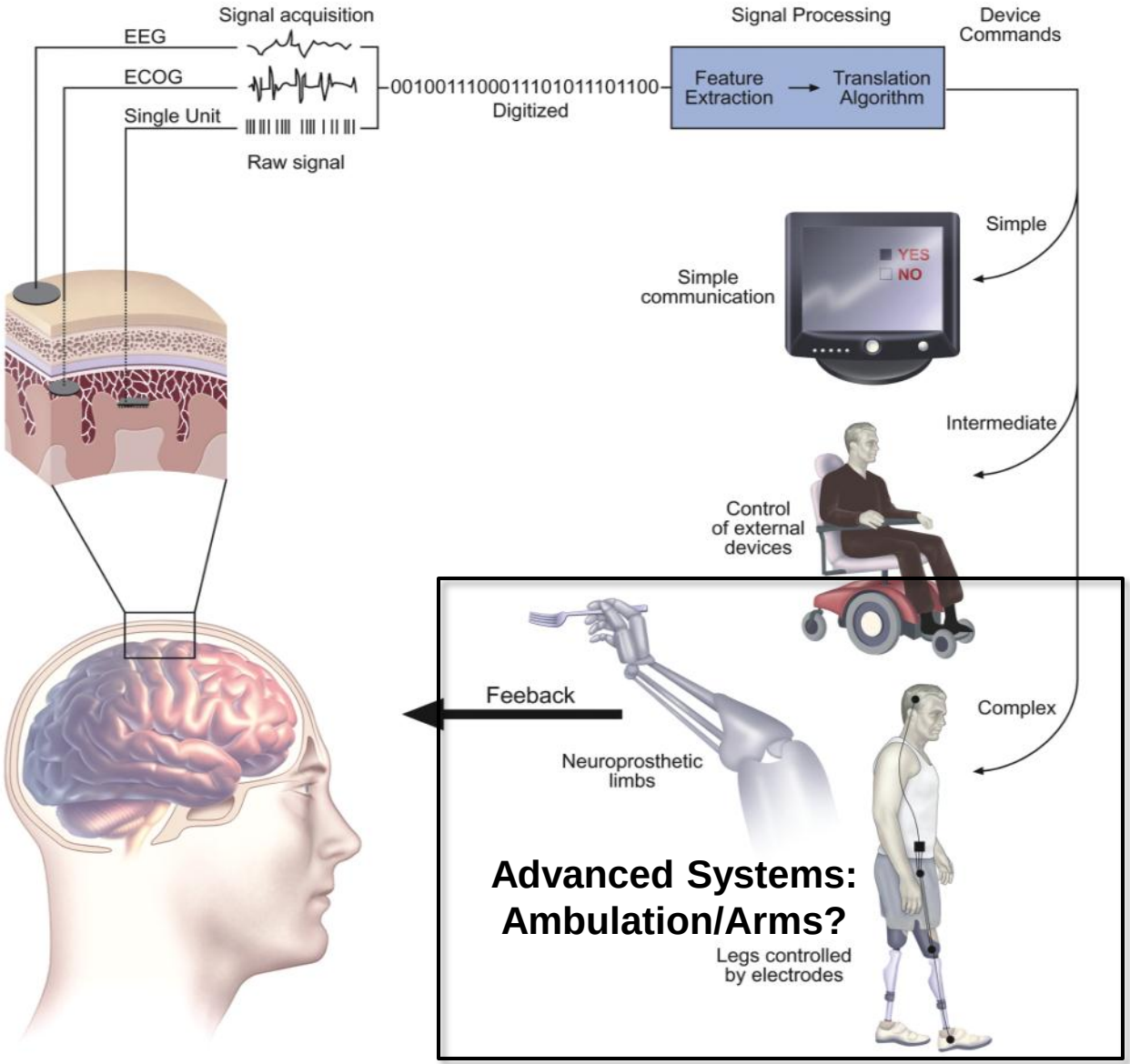
For translation…do we *really* understand value proposition?

- For Consumers (Patients)
- …Clinicians and caregivers
- …Reimbursement agencies

The Value Profit Chain
Heskett, Sasser, Schlesigner
Harvard Business School
The Free Press

Think of as extension of **Benefit**/Risk (regulatory)

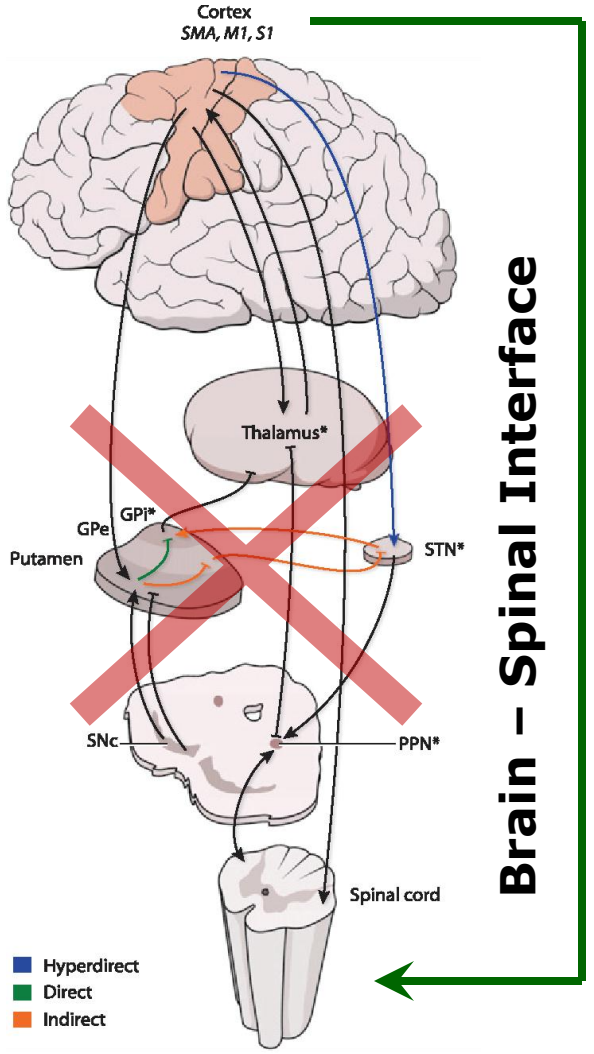
Example 1: More Advanced Applications for Amputees/SCI
Aligning Technology Capabilities → Unmet Need



Leuthardt et al, Neurosurgery, 2006

Motor Control "Bypass" Concept (EPFL NeuWALK)

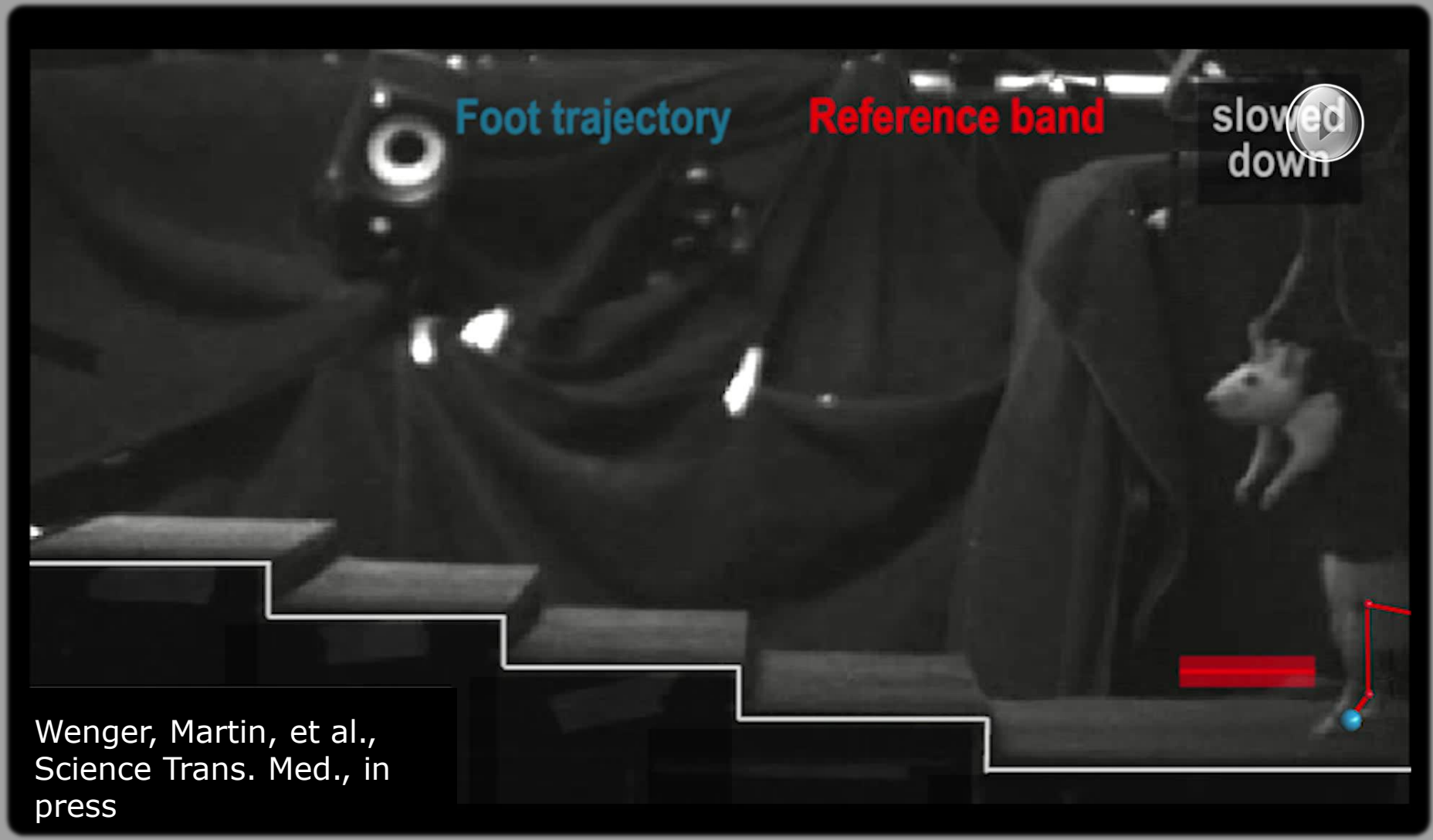
Motor control network



Lozano and Lipsman, 2013

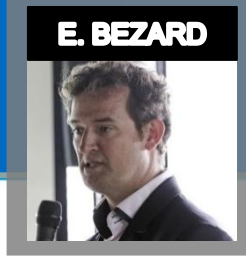
- Neuronal disorders and injuries can interrupt normal functioning of the motor control system
- In some disorders connection between cortex and spinal cord is interrupted
  - Parkinson's disease
  - Brainstem stroke
  - Spinal cord injury
- Introduction of a prosthetic brain-to-brain and cortex-spinal connection to explore alleviating motor symptoms

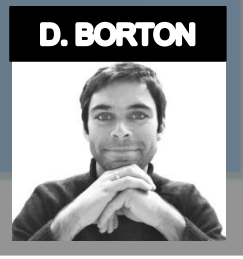
Control of Rat Locomotion by Spinal Cord Stimulation



Wenger, Martin, et al., Science Trans. Med., in press

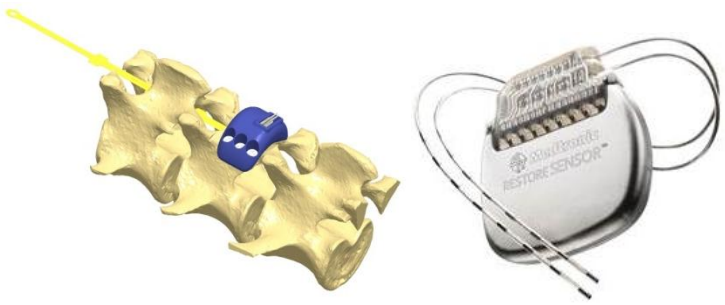
Example of Brain-Spinal-Interface Research Platform



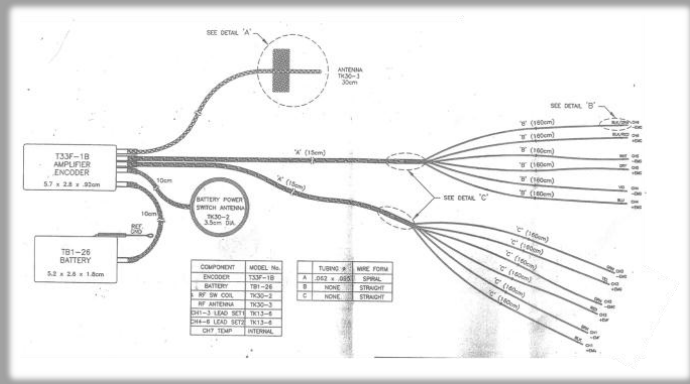


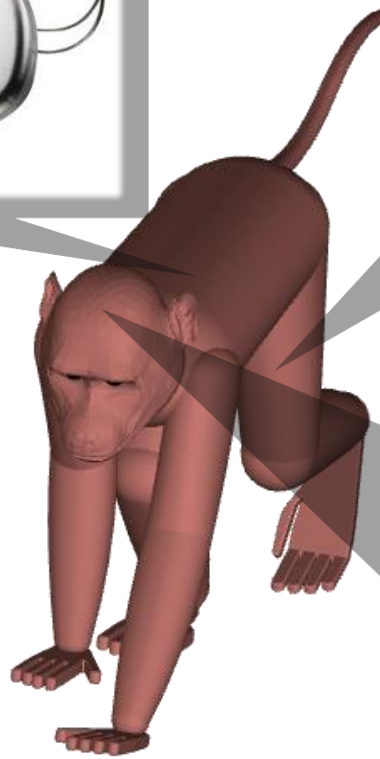
Development Concepts Only – Not for Commercial Sale.

WIRELESS SPINAL STIMULATION



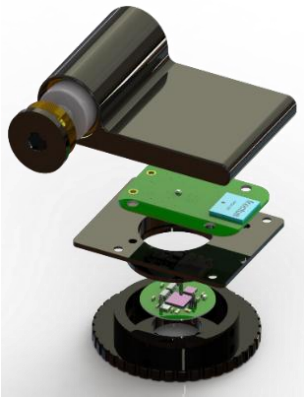
WIRELESS EMG SYSTEM



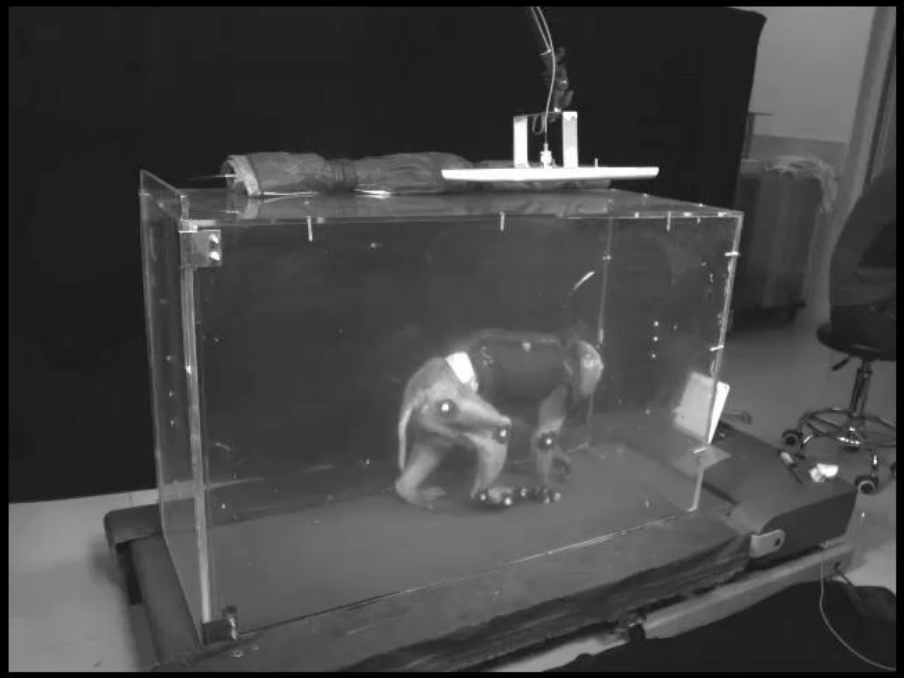


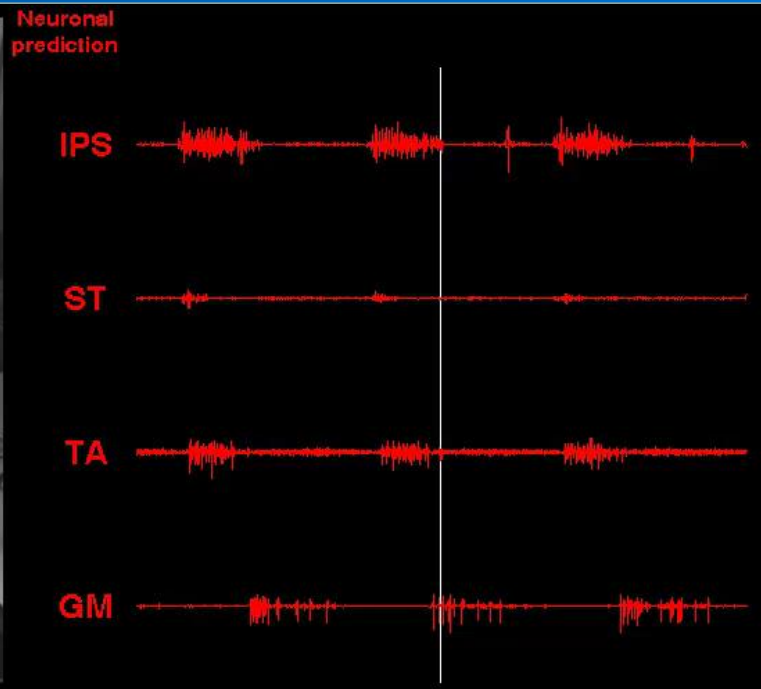
LOCOMOTOR STATE DECODER

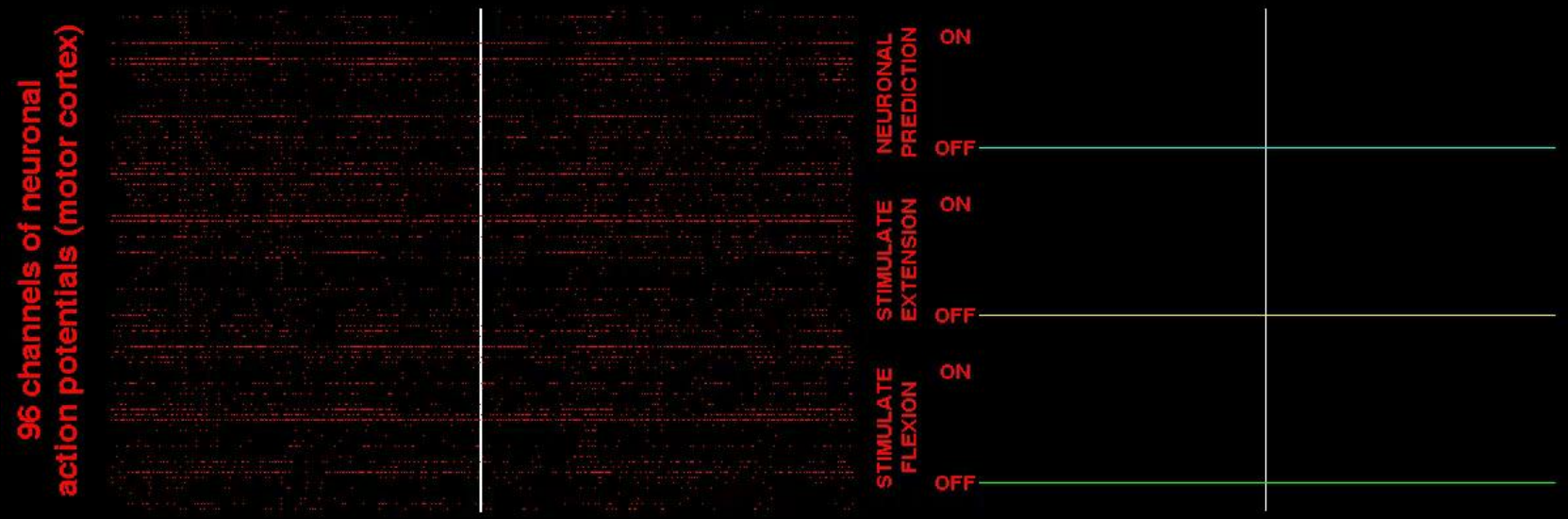
WIRELESS NEURONAL RECORDINGS



Pilot Feasibility of Implanted System with Controller







As we learn: Define a pathway for *Delivering* ***Value***

$$\frac{\text{Results + Process Quality}}{\text{Customer Access Costs + } \textit{Price}}$$

For translation…do we *really* understand value proposition?

- Results: Metrics for Success?
- Process: Set-up, Calibration, Robust Design?
- Access Costs: Complexity?
- Price: Modular Reuse?

The Value Profit Chain
Heskett, Sasser, Schlesigner
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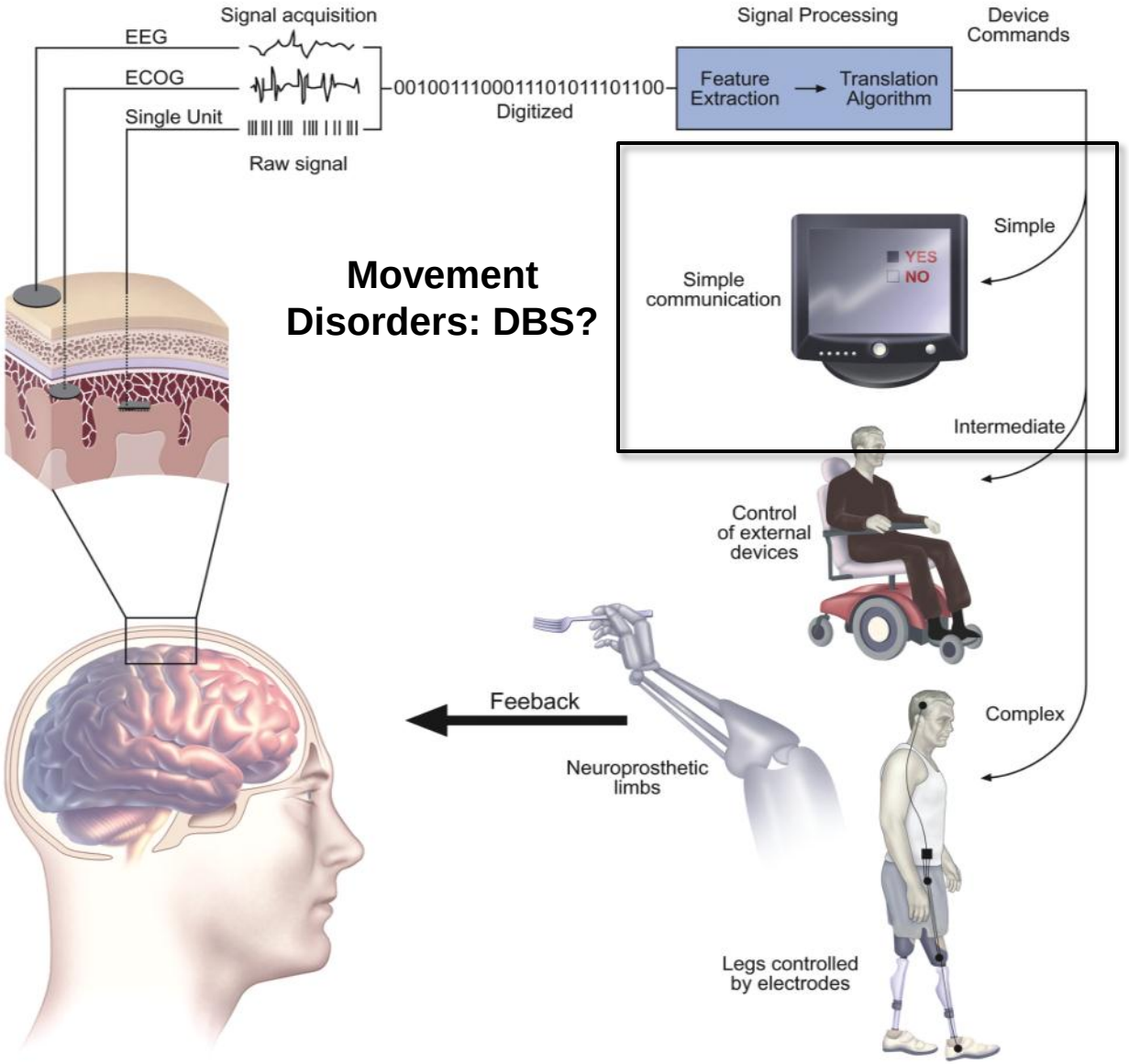
The Free Press

Example 2 from Existing Neuromodulation Roadmaps:
Discuss concepts that might provide insight for SCI/amputee applications

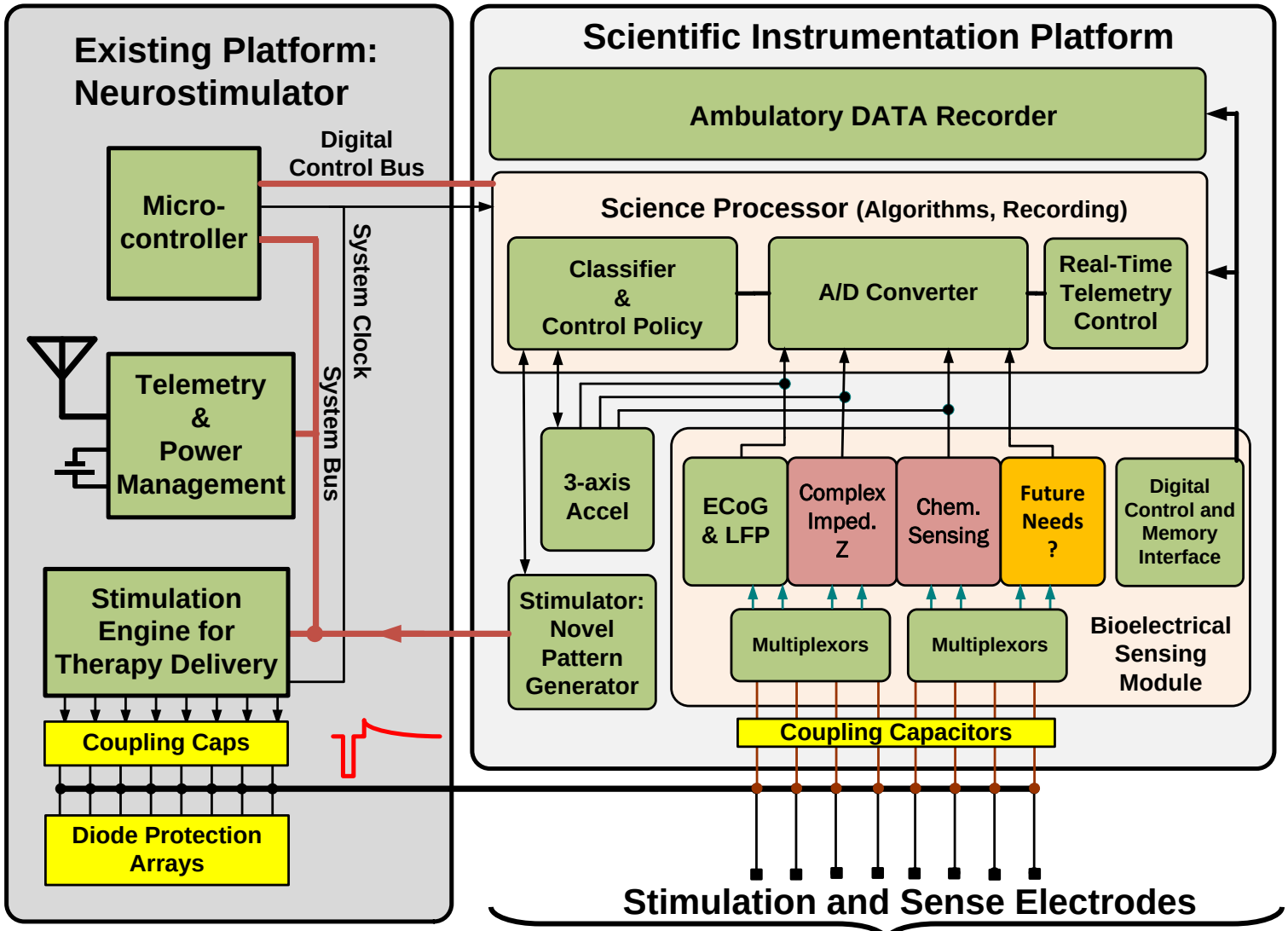


Leuthardt et al, Neurosurgery, 2006

Potentially Improving Modulation of Neural Circuits: Essential Tremor Patient with Device Off/On

Comparing Stim & No-Stim

Modular, Translational Tools for Neural Systems Prototyping



Rouse et al, Journal of Neural Engineering, 2011

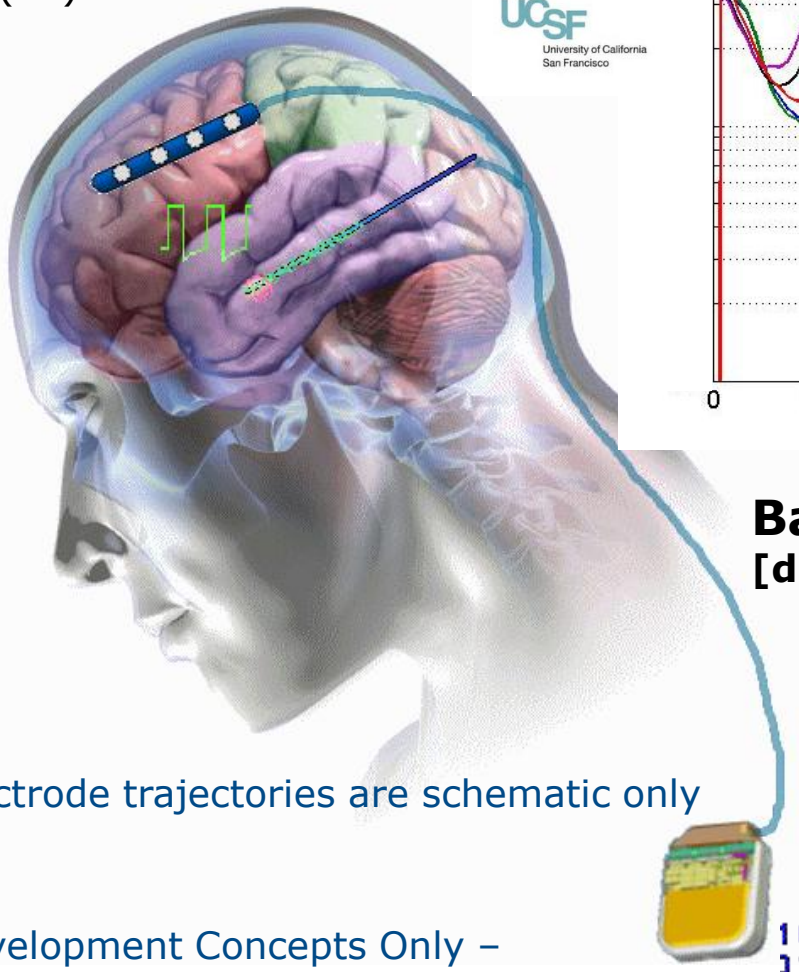
Stanslaski et al., IEEE Neural Engineering, 2011

Flexible Physiology Toolkit
(Embedded Science Payload)

Technology Example: Representative Field Potentials of Physiological Signals tied to Medication and Disease

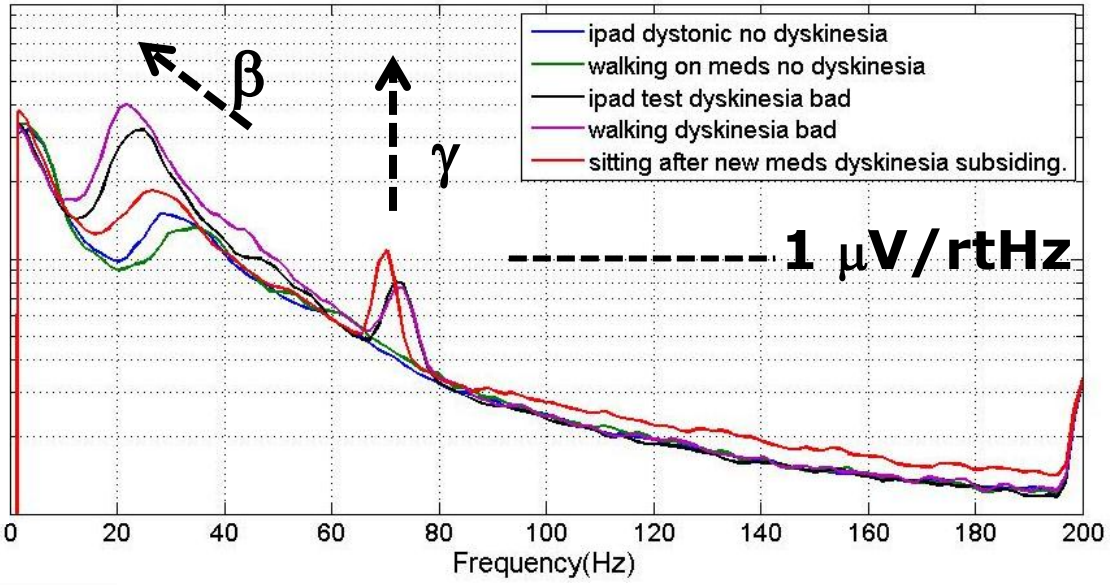
Data Courtesy of Starr and Swann (UCSF)
Analysis and Graphs by MDT

Proc Natl Acad Sci U S A. Mar 19, 2013; 110(12): 4780–4785.



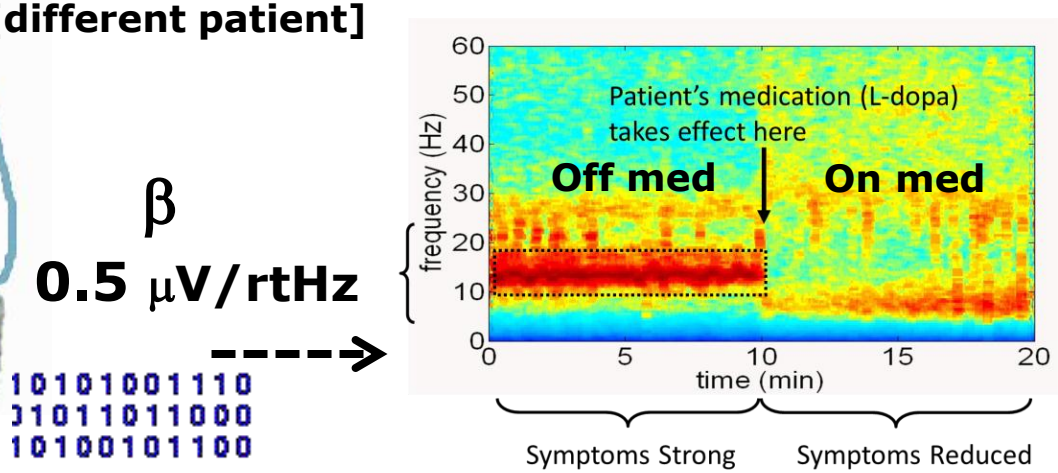
Electrode trajectories are schematic only

Motor Cortex Signals



Basal Ganglia (STN) Signals
[different patient]

β
0.5 μV/rtHz



1010100111
0110110100
1010010110

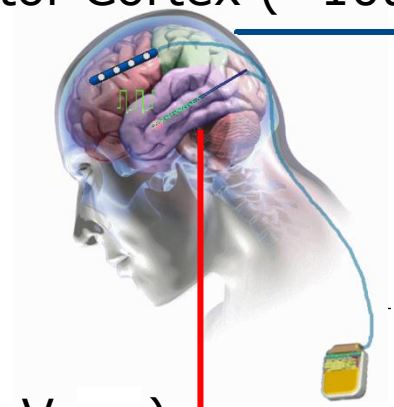
Development Concepts Only –
Not for Commercial Sale.

Potential Pivot: BMI–like Signals in Movement Disorders ?

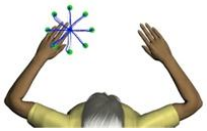
Data Courtesy of Starr and Swann (UCSF); Analysis and Graphs by MDT

UCSF University of California San Francisco

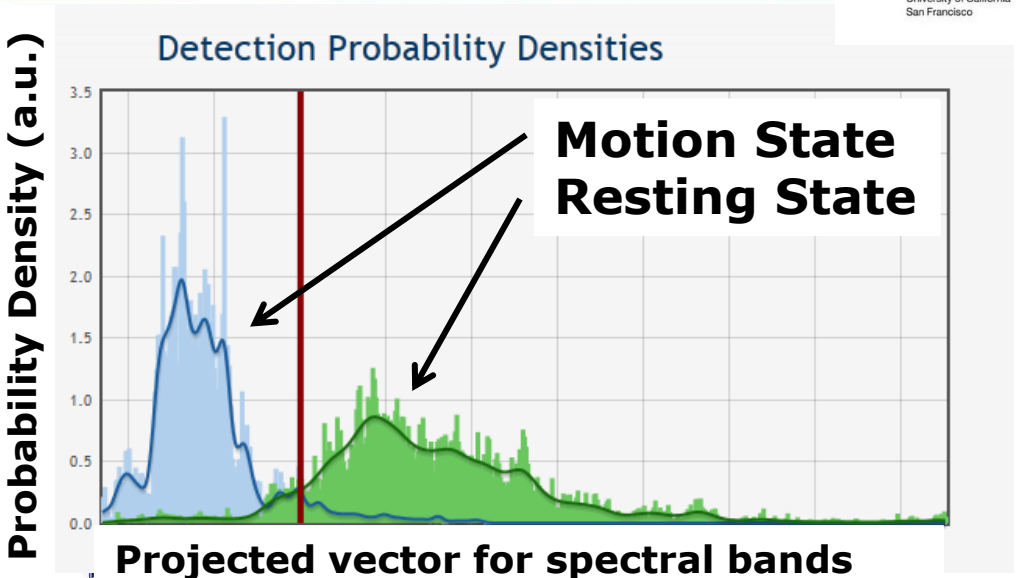
Motor Cortex (~10uVrms)



STN (~1uVrms)



motion



β Band Power (a.u.)

5s

Time

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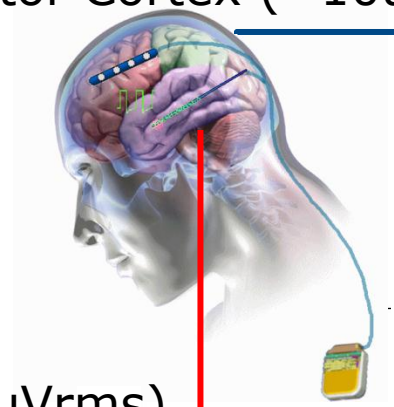
Potential Pivot: BMI–like biomarkers extracted from MvD

Data Courtesy of Starr and Swann (UCSF); Analysis and Graphs by MDT

Motor Cortex (~10uVrms)



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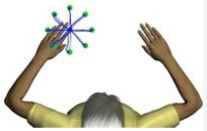
(~1uVrms)



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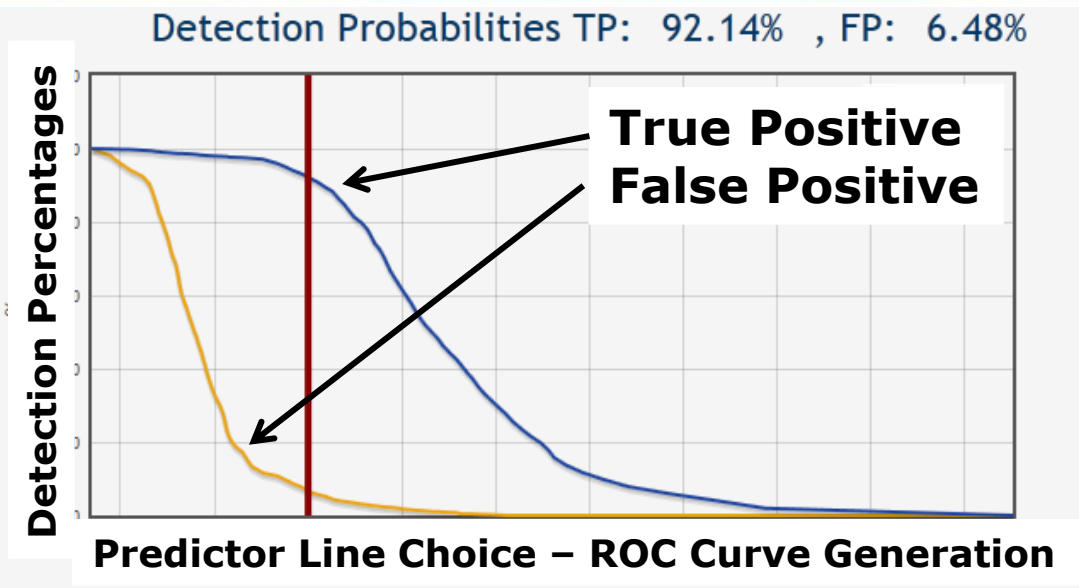

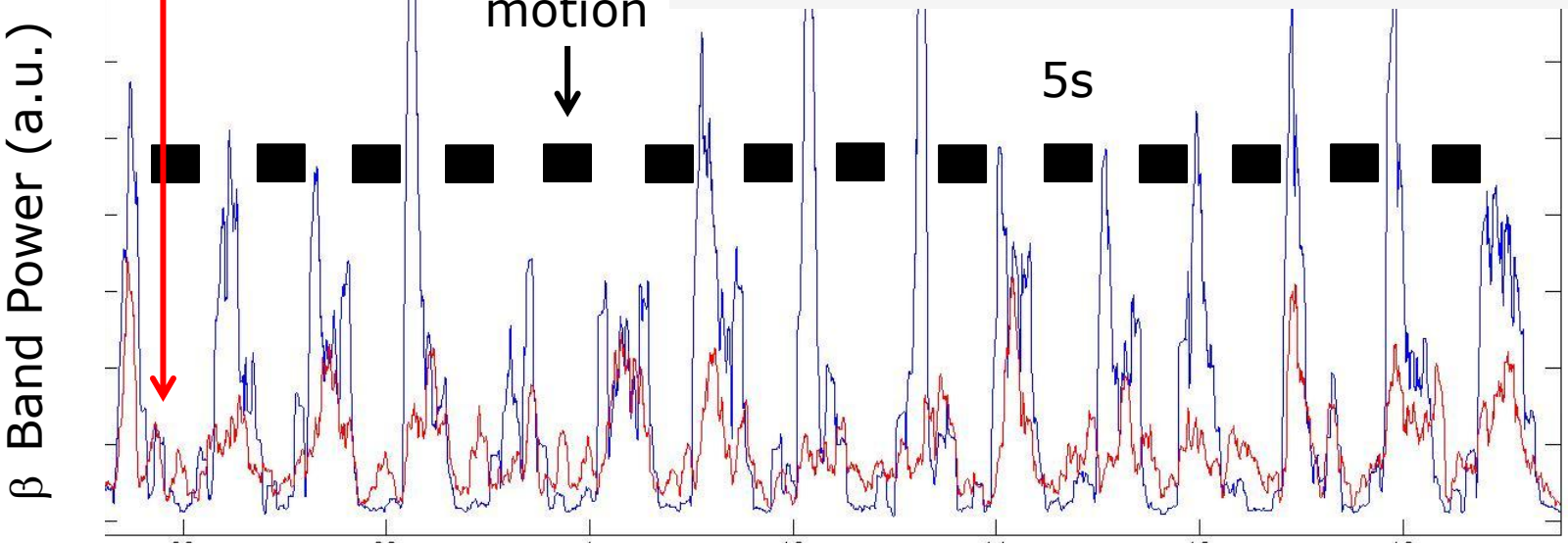

Development Concepts Only –
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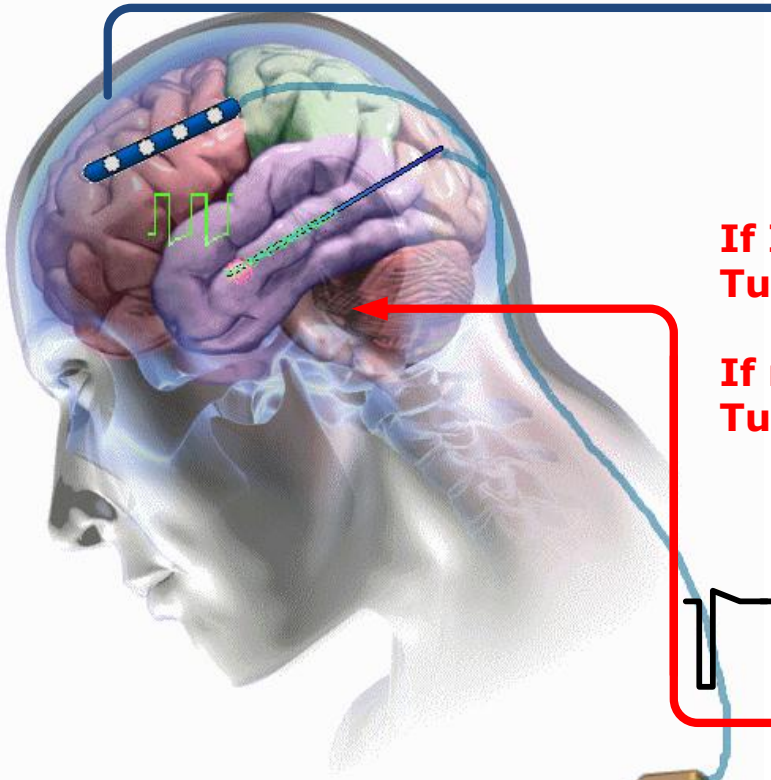
Link "BMI" Detector to Stimulator for Embedded Control?

Illustrates Strategy of Mapping Building Blocks to Unmet Need



Field Potential (ECoG)

Classification:
Signal Amplification
Analysis & Feature Extraction

Estimated Patient "State:"
Intention to Move?

Control Policy:
Map Estimated State to Appropriate Therapy

If Intention is to Move…
Turn on Stimulator

If not …
Turn it Off

New Therapy Parameter update

Actuation:
Stimulator Engine

Development Concepts Only –
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CENTER FOR SENSORIMOTOR NEURAL ENGINEERING

J. Herron and H. J. Chizeck. **Prototype Closed-Loop Deep Brain Stimulation Systems Inspired by Norbert Wiener**. In the Proceedings of the IEEE 2014 Conference on Norbert Wiener in the 21st Century, Boston, MA, June 2014.

Consideration of Delivering ***Value:***
Putative Trade-offs to Consider [value new > old?]

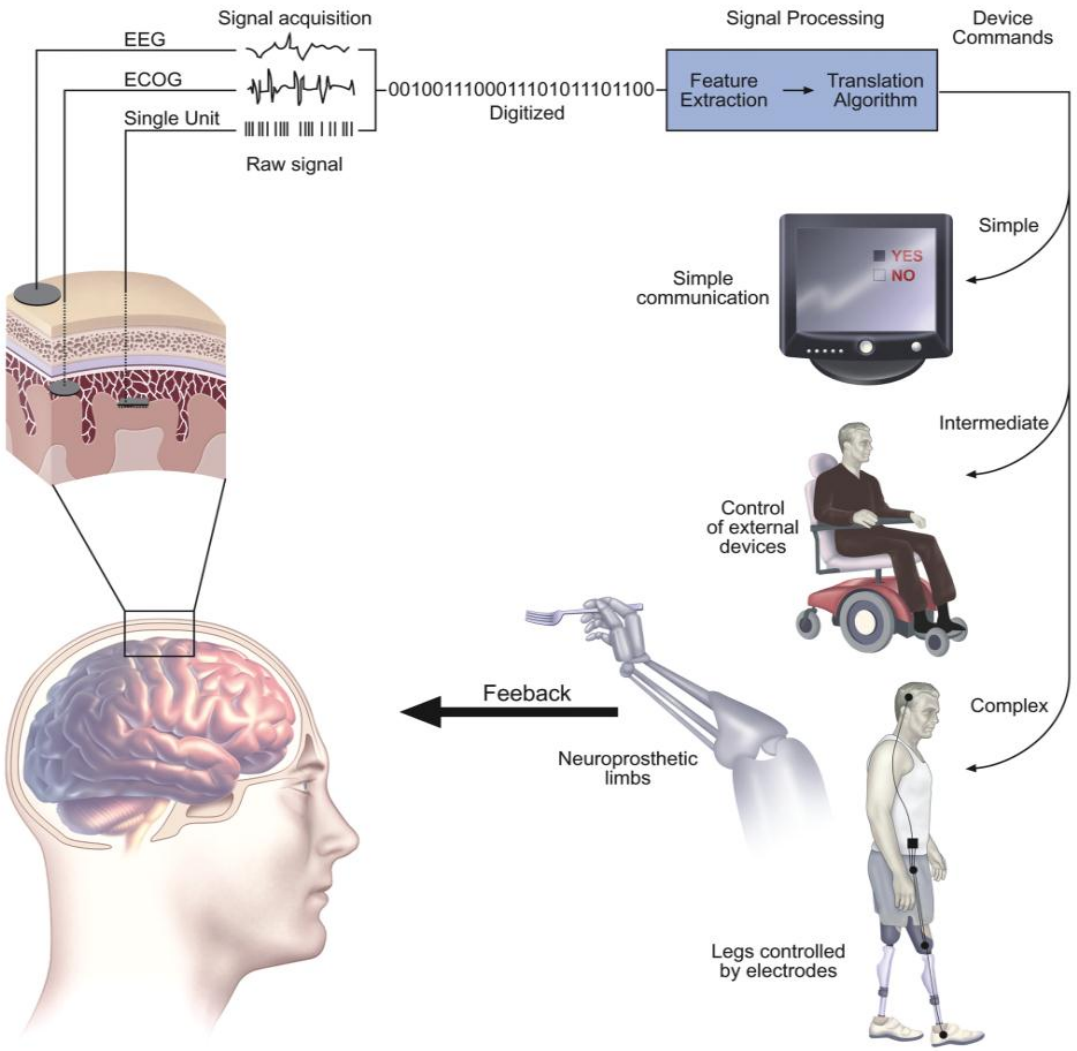
$$\frac{\uparrow \text{Results} + \downarrow \text{Process Quality}}{\uparrow \text{Customer Access Costs} + \textit{Price}\downarrow}$$

Understanding the value proposition?

- Results: Reduce side-effects?
- Process: Requires tuning
- Access: More electrodes
- Price: Improves longevity?

Note: often requires early feasibility research to work these trade-offs out!

Key Opportunity for Industry-Academic-Government: Defining a Translational Roadmap that Delivers Value



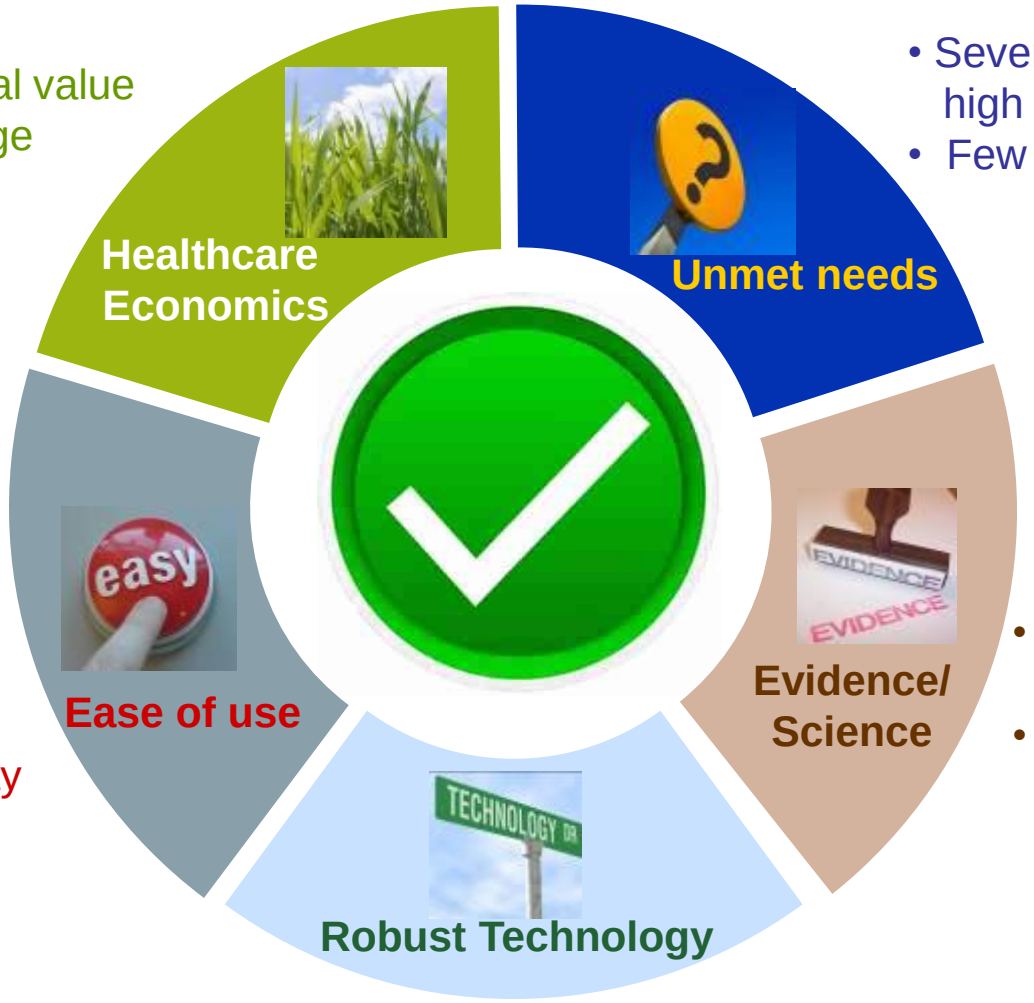
Industry Challenge:
- 24/7 operational environment
- Economically viable
- Robust performance metrics
- Scalable solutions

Academic Challenge:
- Advance technology
- Explore new indications
- Define new metrics
- Establish feasibility

Government Challenge:
- Near-term partner with industry for translation
- Roadmap (re)investment
- Guide problems to be solved … technical, regulatory, clinical, etc

Leuthardt et al, Neurosurgery, 2006

Key Point: Can We Identify Brain-Machine-Interface Applications that *Balance* Design *Constraints?*



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Thanks to Collaborators

Gregoire Courtine

David A. Borton

Starr Lab

Jocelyne Bloch

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ENGINEERING

Ojemann/Ko/Chizeck